BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: A Proposal for a new LM Window/RCS Plume Residue Experiment - Case 310

DATE: November 13, 1967

FROM: R. Troester

## ABSTRACT


An experiment was performed at MSC in February-March, 1966 to determine the amount of deposition of RCS propellant residue on the LM commander's window. Since the results were inconclusive, a repetition, with certain changes, is urged in view of the need of such data in mission planning. The modifications suggested as necessary include the following:

1) Protection of the window samples from atmospheric moisture to guard against residue deliquescence;

2) Simulation of the LM window thermal history during descent;

3) Inclusion of a second pertinent RCS thruster;

4) Simulation of LM surfaces neighboring the windows;

5) Measurements of residue build-up at additional points during the simulated RCS duty cycle, and

6) Additional measurements of the physical characteristics of the residue.

A possible correlation of this experiment with any future Eastman Kodak film studies of lunar lighting conditions is also discussed.

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MEMORANDUM FOR FILE

A great deal of interest has recently been expressed in the possibility of a lunar landing approach against the sun. By allowing a landing in the lunar afternoon as well as at lunar dawn, such an approach would double the number of launch opportunities to a given site and would also take advantage of the excellent scene contrast and surface texture definition available at sun angles near 180°. Unhappily, it is precisely under these good terrain lighting conditions, with the sun in front of the LM and low in the sky (and shining directly on the LM commander's window), that light scatter from any debris on the window would prove the most troublesome.

A major source of any debris on the LM windows is the exhaust plume residue from the upward and forward-pointing Reaction Control System (RCS) thrusters mounted on the ascent stage about 3-1/2 feet from the window surface.* To date, there are no reliable estimates of the amount of residue to be expected, nor the magnitude of scattering it will produce. Both theoretical and experimental evaluations of the degradation of visibility from this source are possible, but the theoretical approach requires certain data (e.g., the debris particle diameter) which can only be obtained experimentally.

It seems clear that the necessary experimental data must be secured by means of tests conducted in a ground-based vacuum chamber and not in space. Astronaut observations of the LM window debris during future earth-orbital LM flight tests are of course extremely desirable. They cannot, however, be relied upon alone to produce the required information for three reasons:

1. It is desirable to obtain the data as far upstream from the Lunar Landing Mission (LLM) as possible in order to incorporate it into mission planning; waiting for a manned LM operations mission would mean a year or more of delay;

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*The pyrotechnics that separate the Spacecraft/LM Adapter and outgassing have been suggested as two other sources. A study of their effects is not included in the present proposal.

2. It would be practically impossible to simulate the lunar landing LM window temperature history and RCS duty cycle during orbital operations, and

3. Any photometric measurements beyond a simple visual inspection for residue and scattering would be difficult to conduct in the LM and awkward to integrate with other astronaut activities.

Some ground-based work on this problem has already been done. A generally well designed but limited experiment[1] was performed at the Manned Spacecraft Center in Houston, Texas in February and March of 1966 to gather the required data, but the results were inconclusive. To carry out the experiment, properly coated sheets of the Vycor glass to be used in the LM windows were mounted in the 20-foot diameter vacuum chamber of the Auxiliary Propulsion Test Facility at MSC and exposed to the exhaust of a full-scale RCS thruster through a simulated duty cycle. Transmission and scattering through the glass were then measured photometrically. Compared to the pretest values, transmission decreased by 25% and scattering, though still small, increased by a factor of 10 to 40. However, as noted in the report on the experiment, certain physical characteristics of the residue and limitations of the experimental set-up make the application of these results to the LLM quite doubtful.

In view of this, it is urged that a new LM window debris experiment be conducted, using the facilities available at MSC. In order to produce reliable data, certain modifications to the experiment will be necessary. The following is a summary of these modifications and suggestions for extending the usefulness of the experiment:

1. Residue change of state. The residue, due to its hygroscopic nature, is crystalline in a high vacuum but changes to an oily liquid at one atmosphere, with a corresponding change in optical properties. This should be guarded against by maintaining the residue in a desiccated environment during the photometric tests and using a "dry-box" for sample transport.

2. Differences in window thermal history. The principal constituent of the residue can exist in five different crystalline forms according to the temperature. Its rate of crystallization is also temperature dependent. Hence, the temperature of the test window must simulate that of the LM during lunar descent.

3. Differences in thruster configuration. The plume deposition on the window due to both pertinent RCS thrusters should be simulated, rather than that of only one as in the original experiment. The different location and orientation of the second thruster makes a reliable extrapolation from the data for a single thruster impossible.

4. Differences in plume environment. In order to establish the proper boundary conditions, the LM surfaces contiguous to the window and RCS quad should be simulated. A shielded glass sample should be included to gauge plume reflection from the walls.

5. Measurements of residue build-up. Measurements of the residue should be made at simulated hi-gate and touch-down, where the visibility problem is most acute, as well as at simulated CSM rendezvous, where it was measured in the original experiment.

6. Further measurement of residue physical properties. Microscopic, refractometric and chemical tests should be performed on the window deposits in order to provide needed information for the theoretical studies. A control run should be made, before the residue experiment proper, to determine that the handling procedures are adequate to preserve the properties of the samples until all the measurements can be made.

7. Correlation with Kodak visibility studies. Any future Eastman Kodak films of lunar landing approaches could use simulated "dirty" LM windows in front of the camera, guided by the results of this experiment, to more accurately show the true terrain visibility in landings against the sun.

The above points are developed further in the accompanying attachment.

Robert Troester

2013-RT-srb R. Troester

Attachment

SUGGESTIONS FOR NECESSARY CHANGES IN EXPERIMENTAL PROCEDURE FOR A NEW LM WINDOW/RCS RESIDUE EXPERIMENT

## I. Residue Change of State

In the test report of the experiment done at MSC[1] it is stated that the residue was observed to undergo a change of state from a dry, white powder to a clear, oily liquid as the ambient pressure rises above .01 $lb/in^2$. Since the ambient pressure during the test runs could not be reduced below .05 $lb/in^2$ and since the photometric tests were conducted at normal atmospheric pressure, the scattering and transmission values obtained do not really apply to the LLM, where the ambient pressure will be essentially zero. This is the most serious deficiency of the original residue experiment.

It is implied in the test report that the change in state is due to the difference in pressure. If this were true, then in order to simulate LLM conditions, the photometric tests would have to be conducted in an evacuated chamber, and an extremely tight vacuum chamber and high evacuation rate pumps would be necessary for the RCS firings, a very difficult and expensive task. But on general physical grounds it seems highly unlikely that such a small pressure as .01 $lb/in^2$ could produce such a change in state. It is most probable that it is not the absolute pressure of the ambient air that affects the residue, but rather the partial pressure of any water vapor which may be present.

The residue in question is the complex combustion product of the inhibited nitrogen tetroxide oxydizer and Arazine-50 (50% hydrazine, 50% UDMH) fuel. Its composition is not completely known, and indeed the composition of the residue on the window has never been studied. It is believed, however, that it is similar to that found in the RCS nozzle after engine test runs. Workers at the Thermochemical Test Branch at MSC have described this residue as a fine hygroscopic whitish-tan powder which will absorb enough water from the atmosphere to completely dissolve within one hour after air is admitted back into the test chamber.[2]

The hygroscopic nature of the residue is confirmed by the latest information on it due to H. Purlee of the Bureau of Mines, which has been performing analyses of the residue for MSC. He describes the residue as it would form on the window in a vacuum as composed of needle-shaped crystals of ammonium nitrate (an extremely hygroscopic crystal) in a thin layer of a non-volatile straw-yellow mother liquor, a concentrated solution of various nitrates and perhaps azides or nitrites. Water would initially be present as a reaction product, but would evaporate under zero pressure.[3]

Since the observed change of state between the vacuum and normal pressure forms of the residue seems entirely due to the deliquescence of the crystals, reliable scattering and transmission tests can only be made if they are performed in a desicated environment, e.g., a bell-jar with a drying agent such as silica gel. The window samples should be transported from the firing chamber to the photometer in some type of a "dry box", and to minimize contamination during the fifteen minutes it takes to repressurize the firing chamber, some sort of remotely operated cover should be placed over the window samples at the conclusion of the test unless it can be arranged to use a source of dry air in refilling the chamber.

## II. Differences in Window Thermal History

The temperature of the window samples may be a very serious problem. In the LM the inner pane of the commander's window will be heated by a resistive antifog coating applied to the outer surface; the outer pane is not heated (except by conduction from the surrounding LM structure). The gap between the inner and outer panes is vented to space. Since the Vycor glass of which the outer pane is made has a low thermal conductivity, its surface temperature will depend primarily on the amount of solar radiation reaching it during the descent. Present planning calls for the LM to remain face down toward the lunar surface for the greater part of the descent to hi-gate to allow landmark sightings. Thus, for a landing either in lunar morning <u>or</u> afternoon the outer pane will have been in solar shadow and be quite cold up to hi-gate. In a morning landing the window will remain in shadow until touchdown, assuming a dog-leg maneuver is not included, while in an afternoon landing the window will be exposed to full sunlight from hi-gate to touchdown, and its temperature should rise considerably.

The thermal history of the window is important, since ammonium nitrate, believed to be the principal constituent of the residue, exists in five different crystalline forms, depending on the temperature. For example, below 0°F it is a tetragonal crystal, while from 0°F to 90°F an orthorhombic structure is more stable. The physical characteristics of the residue, such as the index of refraction, hence can be expected to vary radically with temperature. The amount of residue on the window will also be a function of temperature, as crystals find it easier to form at lower temperatures. Thus it may well prove the case that there will be a larger residue buildup in the nominal approach with the sun behind the LM than during a landing against the sun where the residue will evaporate from the hot window surface.

Duplicating the LM window temperature during the whole residue experiment is an awkward task and was not attempted in the previous experiment at MSC. It is clear from the above discussion that in any new experiment the temperature must be controlled throughout the entire process of exposure and measurement for much confidence to be placed in the results. It is desirable that runs be made at both high and low temperatures to determine the amount of residue formed on the window during both nominal and against-the-sun approaches.

## III. Differences in Thruster Configuration

In the MSC experiment the window samples were exposed to the exhaust plume of one RCS thruster in the relative orientation of thruster I-u on the LM, the upward-pointing thruster near the commander's window. But the plume from thruster I-f, which points along the +Z axis in the same quad, could also contaminate the window. Furthermore, one of the -x SM-RCS thrusters, and, to a much lesser extent, the LM descent and ascent engines may possibly contribute some residue. Considering the distances to the window and direction of exhaust, the contribution of these last three sources compared to that of the LM's own RCS must be quite small and may properly be ignored in this simulation. On the other hand, the effect of thruster I-f cannot be ignored nor should it be merely extrapolated from that of thruster I-u. Its inclusion can be expected to roughly double the total contamination, but the location and orientation of I-f are sufficiently different from that of I-u to make it necessary to check this assumption experimentally.

In the original MSC experiment only one RCS thruster was available. If this still proves to be the case, the single thruster could be fired in thruster I-u's simulated duty cycle, rotated 90 degrees, and fired again in simulation of thruster I-f's cycle. (The window sample should be properly protected against moist air, if the chamber must be breached in order to shift the thruster.) If a second thruster is available, its use would, of course, simplify the procedure (and complicate chamber pumping problems). In any case its contribution to the total contamination must be included in the simulation to provide reliable scattering and transmission figures.

## IV. Differences in Plume Environment

In the original residue experiment a welded pipe stand was constructed to hold the window samples in the proper orientation in relation to the thruster. But no provision was made for simulating the contiguous LM surfaces around the LM window and thruster in order to guide the plume as it will be guided on the LM. This could be carried out fairly easily with the aid of sheet aluminum panels installed about the window position.

However, there is another difference in the plume environment between the vacuum chamber and free space conditions which would be more difficult or impossible to correct and which should be noted. The very fact that the experiment must be conducted in a closed chamber means a certain amount of reflection from the spherical walls of the chamber and perhaps a greater window contamination than would be the case in free space. It is impossible to prevent this, but is magnitude can be roughly gauged by the contamination measured on glass samples placed near the window position but shielded from direct plume bombardment. These samples would also aid in determining the effect of the general rise in chamber pressure from about 50 microns to .1-1 mm which takes place during the test.

A final environmental difference lies in the possibility of chamber contaminants. It is probable that any such contamination would be quite small, the major contributions coming from dirt which has collected under the grill floor of the chamber and from the painted walls of the chamber, but some effort should be made in any future work to reduce it to a minimum.

## V. Measurements of Residue Build-Up

In the previous experiment at MSC, the scattering and transmission through the samples were measured only after the thruster had gone through a complete duty cycle, that is, at simulated rendezvous with the CSM. Yet it is of more interest, in considering the possibility of an against-the-sun approach, to measure the degradation in visibility at simulated hi-gate and at touchdown. From a comparison of firing times, it is expected that the residue build-up at hi-gate and touchdown should be about 40% and 55%, respectively, of the total build-up, but these figures should be checked.

## VI. Further Measurements of Residue Physical Properties

In the original work at MSC, two types of measurements (beyond simple visual inspection) were made on the sample, a transmission test and a scattering test, both performed with natural white light. It would be desirable to repeat these tests in the new experiment for two reasons: a) because they directly measure the degradation of vision the astronaut will experience when sighting through the LM windows, and b) in order to verify the somewhat anomalous behavior of the scattering function fround previously. However, some other tests should also be made to learn more of the relevant properties of the residue, such as the shape, size distribution, transparency and refractive index of the scattering particles, to give more confidence to the theoretical models which are being used to analyze the whole glare problem.

The simplest and most powerful additional measurement is a microscopic inspection of the window residue. If, as presently seems the case, the scattering particles forming the residue are reasonably larger than a wavelength of light, their concentration, shape, size and size distribution can all be simultaneously measured by this means. The refractive index of film plus scatters can be measured by means of a common refractometer; this, together with the extinction measured in the transmission test, serves to define the complex refractive index of the composite medium, which is needed for the scattering model.

Besides the scattering test made with natural white light, the same test should be repeated using monochromatic polarized light. The use of the monochromatic light will sharpen the scattering distribution and make a more accurate determination possible. If the microscopic examination cannot be carried out for some reason, some of the same results can then be derived from this scattering test. And, finally, a quantitative chemical analysis should be made of the window residue to confirm that it is of the same composition as that which is found in the RCS thrusters.

In order to provide some assurance that the handling procedures and experimental technique described above are adequate, a control run should be made before the residue experiment proper. One possible difficulty that can be checked during this run is the rate of crystallization of the residue. It may be that even the 15-minute chamber repressurization time is long enough that the crystals in the film of mother liquor will grow sufficiently to produce misleading values in the tests. To verify whether or not this is true, a remotely controlled camera could photograph the residue as it is being deposited during the check run.

## VII. Correlation with Kodak Visibility Studies

The Eastman Kodak Co. has completed two motion picture studies of the lunar landing for MSC using a stop-motion technique on a model lunar landscape dusted with cupric oxide. In general, the motion picture simulations are quite useful in that they close the gap between what is known of the lunar surface reflection characteristics on the one hand and what is known of the eye's contrast detection characteristics on the other, the very gap which the theoretical studies have not been able to bridge. However, the films were designed only to portray surface shadowing characteristics under different lighting/viewing conditions. Therefore they do not truly represent what the astronaut would see during a landing approach since those portions filmed against the sun do not include the degradation of visibility due to scatter off the LM window and solar dazzle in the astronaut's eye. In some cases they do show a false glare effect, due to reflections from the simulated sun off the lens barrel and within the camera. Even in approaches with the sun behind the camera, the present films do not show the effect of scatter on the window of light reflected from the lunar surface (an order of magnitude less serious than solar scatter).

If further motion picture studies are carried out at Kodak, the results of the residue experiment could be used to improve the fidelity of the simulation. Once the scatter and absorption characteristics of the residue have been accurately determined, it may be possible to find a more stable substance which, when coated on a window sample, will duplicate the residue's optical characteristics. Such a sample could then be mounted at the correct angle on a lens shade in front of the camera used in the film studies. The sun shade would block the false glare effect (at least where the light source is not in the direct field of view) and the scatter from the coated sample would simulate that from the LM window. The effect of solar dazzle in the astronaut's eye would be more difficult to include. Perhaps it could be simulated by the equivalent veiling brightness of light reflected from a glass sheet held in front of the camera, as in the experimental work of Holladay and others who have studied glare.

The inclusion of the twin effects of scatter and dazzle in the Kodak studies would contribute much toward making the films an accurate visual simulation of the conditions during a landing on the moon.

RT/srb
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## REFERENCES


1. Lee, Jeanne N., "Apollo Thruster Residue Evaluation", NASA/MSC Internal Memorandum CF325-6M-151, 25 April 1966.

2. Personal communications with Allen H. Watkins, Acting Branch Chief, Thermochemical Test Branch, Propulsion and Power Division, MSC.

3. Personal communication.

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